Chapter 71

EVALUATION OF PERSONAL DIESEL PARTICULATE SAMPLERS

by

Mr. Robert A. Haney
Mine Safety and Health Administration
Supervisory Mining Engineer
Pittsburgh, Pennsylvania

Mr. Richard T. Stoltz
Mine Safety and Health Administration
Mining Engineer
Pittsburgh, Pennsylvania

ABSTRACT

In July, 1988, the Mine Safety and Health Administration (MSHA) Advisory Committee on Standards and Regulations for Diesel-Powered Equipment in Underground Coal Mines recommended that the Secretary of Labor set in motion a mechanism whereby a diesel particulate standard can be set. Prerequisite to establishing a standard would be the development and evaluation of instrumentation to measure diesel particulate. In response, the Mine Safety and Health Administration, Dust Division, has been evaluating instrumentation that can be used to determine diesel particulate levels in underground mines. This instrumentation employs the principle of impaction to separate particles by size, thereby, separating the diesel and nondiesel particulate. Separation of the particulate by size was chosen because diesel particulate is generally less than 1.0 micrometer in size. No other methods have been developed to successfully distinguish between the coal and diesel particulate.

MSHA developed an impactor that is inexpensive and compatible with existing pumps and filter holders. The instrumentation evaluation has primarily focused on the repeatability and performance of several personal dust samplers. The samplers tested include the Sierra-Andersen Model 298 personal impactor and MSHA developed personal impactor. The MSHA impactor is inexpensive and compatible with the existing pumps and filter holders. In addition to evaluating the precision and performance of these instruments, tests have been conducted to determine background levels of submicron particulate in nondieselized coal mines and to measure the submicron particulate content in dieselized coal mines. Tests were conducted in coal mines where diesel equipment was used only in outby areas and also in coal mines where diesel equipment was used for face haulage. This paper describes the results of the tests and provides a description of the instrumentation used to conduct the tests.

INTRODUCTION

Diesel-powered mobile equipment has been in use in underground coal mines in the United States for over 10 years. Because of the versatility offered by diesel power, its use has steadily increased. Equipment is used for outby haulage of people and supplies as well as for face haulage and section cleanup. The increased use of diesel power has resulted in increased concerns with respect to the health hazards associated with use of the equipment.

In July, 1988, the "Report of the Mine Safety and Health Administration (MSHA) Advisory Committee on Standards and Regulations for Diesel-Powered Equipment in Underground Coal Mine" (U. S. Department of Labor, 1988) was delivered to the Secretary of Labor. The report addressed three areas of concern: "The approval of diesel-powered equipment, the safe use of diesel-powered equipment and the protection of miners' health." Under the area of health the first recommendation was that "The Secretary should set in motion a mechanism whereby a diesel particulate standard can be set."

In August of 1988, the National Institute of Occupational Safety and Health (NIOSH) issued a report on "Carcinogenic Effects of Exposure to Diesel Exhaust" (NIOSH, 1988). This report recommends that whole diesel exhaust be regarded as "a potential occupational carcinogen." This recommendation was based on animal studies and a study of railroad workers exposed to diesel exhaust. While the study did show an increased risk for those exposed to diesel exhaust, it did not determine the exposure level associated with the increased risk.

Prerequisite to establishing a standard for diesel particulate is the development of a method or instrument to sample the contaminant. This instrument would have to be compatible with field and laboratory constraints which would require the instrument to be light weight, inexpensive, compatible with existing sampling systems and easily analyzed in the laboratory.

The purpose of this paper is to describe the evaluation of prototype impaction devices for measuring submicron particulate levels in

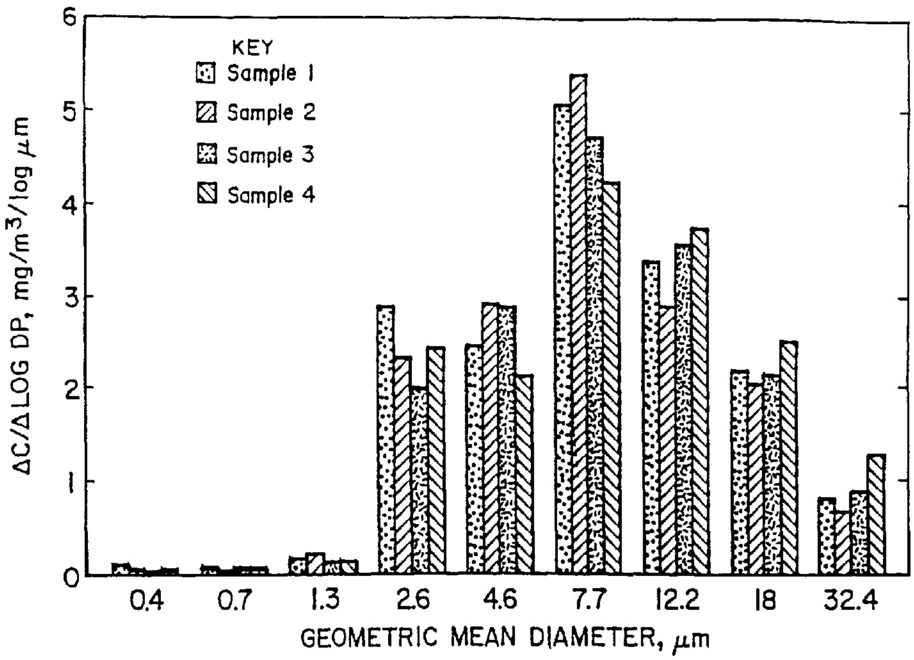

Figure 1. Particle Size Distribution of Simultaneous Impactor Measurements in Nondieselized Underground Coal Mines.

underground coal mines. The evaluation focused on measuring background levels, determining the repeatability and the reliability of the measurements.

BACKGROUND

Selection of an analytical method to distinguish between coal dust and diesel particulate has not been successful. Ashing techniques which remove the respirable combustible dust can be used with noncarbonatious dust, however, ashing techniques are not suitable for analyzing for diesel in coal mines because ashing also decomposes the carbon in coal. Benzene soluble techniques have also been unsuccessful for separating diesel from coal dust as coal dust contains benzene soluble compounds in varying amounts.

The method currently being evaluated to distinguish between coal dust and diesel particulate is based on the size distribution of the dust. Studies have shown that dust generated from crushing of material is generally greater than 1.0 micrometer in diameter. In the respirable size fraction approximately 90 percent (by mass) of the dust generated from crushing material is greater than 1.0 micrometer. Conversely, particulate generated from combustion processes (i.e., fumes) are generally less than 1.0 micrometer. Tests have shown that in coal mines 90 percent of diesel particulates are less than 1.0 micrometer in diameter (Cantrell, 1987).

Figures 1 and 2 show typical plots of the size distribution for simultaneous impactor measurements in nondieselized and a dieselized coal mine. The ΔC/Δ LOG DP (change in concentrations per log of the particles size interval) scale on the "Y" axis is used to provide a visual representation of the dust concentration per unit size. The nondieselized dust samples (Figure 1) show a monomodal distribution with values generally greater than 1.0 micrometer. The dieselized coal mine dust samples (Figure 2) show an additional mode below one micron. The submicron mode is attributed to diesel particulate, the supermicron mode is attributed to coal dust. Additional tests have shown that the separation of the modes for coal mine dust occurs at approximately 0.8 micrometer (Rubow, 1988).

INSTRUMENTATION DEVELOPMENT

Impaction samplers have long been used to determine size distribution of airborne aerosols. It was therefore logical that these types of devices be used to separate the supermicron fraction from the submicron fraction of the dust.

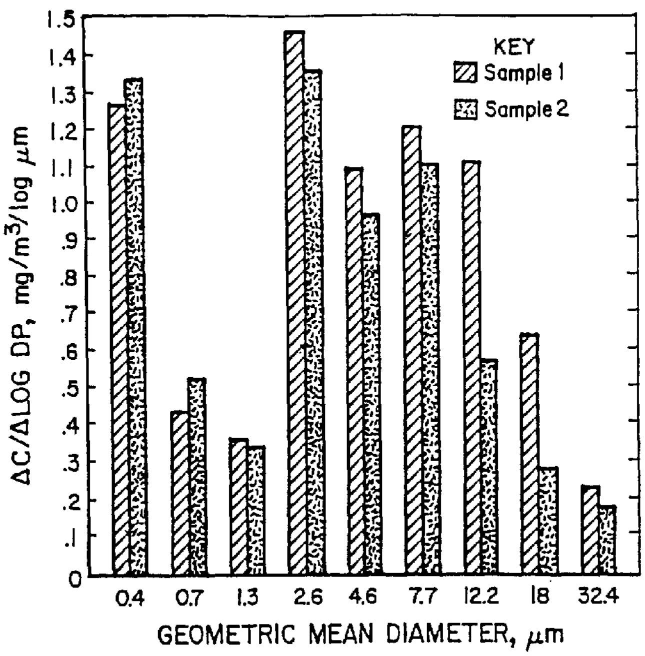

Figure 2. Particle Size Distribution of Simultaneous Impactor Measurements in Dieselized Underground Coal Mines.

Several constraints however were imposed when considering an impactor for sampling in coal mines.

The impactor should be compatible with existing sampling hardware and pumps, and it should be capable of making a determination of both the respirable dust concentration and the diesel particulate concentration. Additionally it should be relatively inexpensive and should provide a sample that is not difficult to analyze in the laboratory.

The Sierra-Andersen Model 298 is an 8-stage impactor which has been used extensively to determine aerosol size distribution. However, its design characteristics do not satisfy the above criteria. The instrument is expensive, requires substantial laboratory preparation and analysis and does not provide a direct measurement of the respirable fraction. A direct determination of the submicron dust concentration can be obtained by adding the concentration from the 0.5 micrometer impaction plate and the final filter.

Recognizing these limitations, NIOSH designed and constructed a single stage impactor to separate submicron from supermicron dust (Stanevich, 1988). The impactor was built from a three piece aerosol monitor. A 10 mm Dorr Oliver cyclone preseparator was used to provide the respirable fraction and a single impaction plate was used to separate the supermicron from the submicron dust. While conceptually simple, there were several problems inherent in the design of the unit. These include the large jet to plate distance, the tolerance of the nozzle, durability of impaction plate and compatibility of the system with the existing coal sampling systems.

MSHA addressed these problems and made modifications to the design to correct them. The three piece monitor was replaced by an MSA (Mine Safety Appliances) filter capsule typically used to sample coal mine dust.

The impaction plate was supported on a 3/8-inch spacer which permitted the entire unit to fit into the standard breast plate sample holder. The aluminum foil impaction plate was replaced with a more durable 0.002-inch thick stainless steel impaction plate. The impaction orifice which had been drilled through an epoxy cement plug was replaced with a machined brass insert that was adjusted so the jet to plate distance was 3.0 millimeters. Schematics of these two designs are shown in Figures 3 and 4. Brass orifice inserts with orifice diameters of 0.8 mm and 1.0 mm were made. According to impactor design theory a 0.8 mm orifice would provide an effective

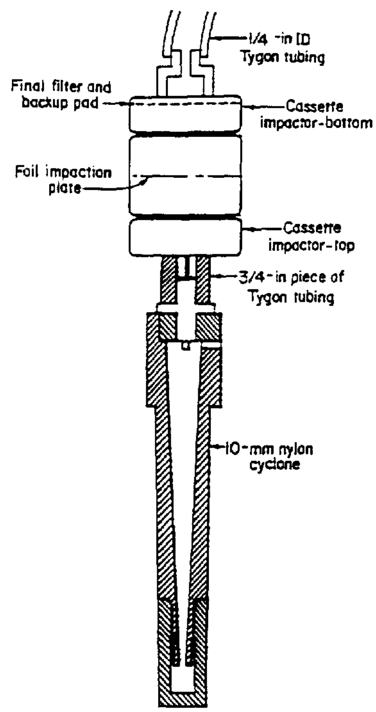

Figure 3. Schematic of NIOSH Submicron Impactor Assembly.

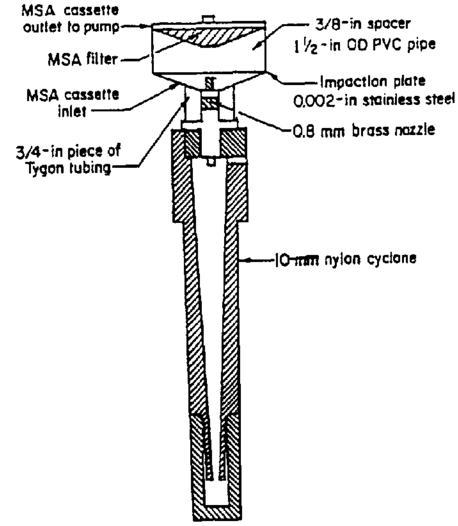

Figure 4. Schematic of MSHA Submicron Impactor Assembly.

cut diameter of 0.8 micrometer. The 1.0 mm orifice would provide an effective cut diameter of 1.0 micrometer (Lodge, 1986). The effective cut diameters of the above impactors (Sierra 298, NIOSH and MSHA) are based on a 2.0 liter per minute flow rate.

INSTRUMENT TESTING PROCEDURES

Instrument testing and evaluation was divided into two phases. In the first phase the Sierra 298 was evaluated in nondieselized coal mines. In the second phase the MSHA impactor was evaluated in both dieselized and nondieselized coal mines.

For the first phase a test package consisting of three or four Sierra 298 impactors, two respirable coal mine dust samplers and two total dust samplers were assembled. The instruments were placed and operated in the section return within 200 feet of the face of an active section. The instrument packages were operated between two and four hours. The return sampling location was selected to ensure high dust levels. The sampling periods were adjusted in an attempt to obtain a dust loading (mass) similar to that obtained during compliance sampling. Samples were collected in three nondieselized coal mines. A total of six sets of samples were collected.

For the second phase of the investigation a sampling package consisting of two to eight MSHA impactors, two respirable coal mine dust samplers and two total dust samplers were assembled. Also included in the package were two Sierra 298 impactors which would serve as a reference of particle size. The package was similarly placed in a return of a working section. Samples were collected in two nondiesel coal mines and in four dieselized coal mines. Three sets of samples were collected in nondiesel coal mines and 10 sets of samples were collected in dieselized coal mines.

All sample filters and impaction substrates were pre- and post-weighed to 0.001 mg. Impaction substrates were coated with grease to improve impaction efficiency. Because particle bounce on impactors can be a problem, varying amounts of grease on the plates were investigated. All sampling pumps were calibrated and operated at 2.0 Lpm. Because each type of sampling device had a different pressure drop, pumps had to be calibrated for the specific type of sampling device used. MSA Model G pumps were used for respirable and total dust samples. MSA Flow-Lite

TABLE 1. SIERRA-ANDERSEN IMPACTOR MODEL 298 SIZE DISTRIBUTION DATA

SAMPLE # 1-D
DATE: 1/06/88
FLOW RATE 2.000 LPM
OP. TIME 310.000 MIN

STAGE #	INIT.WT. MG	FIN.WT MG	CHG.WT. MG	FRACTION %	ECD UM	CUM.FRAC. %	CONC. MG/M3
1	144.815	145.003	0.188	8.199	21.000	100.000	0.303
2	146.219	146.415	0.196	8.548	15.000	91.801	0.316
3	143.841	144.208	0.367	16.005	10.000	83.253	0.592
4	146.589	147.284	0.695	30.310	6.000	67.248	1.121
5	145.161	145.514	0.353	15.395	3.500	36.939	0.569
6	146.850	147.282	0.432	18.840	2.000	21.544	0.697
7	144.800	144.835	0.035	1.526	0.900	2.704	0.056
8	146.687	146.697	0.010	0.436	0.500	1.177	0.016
FILTER	10.706	10.723	0.017	0.741	0.000	0.741	0.027
TOTAL WT.			2.293				3.698
SUBMICRON			0.027				0.044
BMRC-RES							1.142

pumps with a standard battery pack were used for Sierra 298 and MSHA 1.0 mm impactors. MSA Flow-Lite pumps with a heavy duty battery pack were used to operate the MSHA 0.8 mm impactors.

RESULTS AND DISCUSSION

Tables 1, 2 and 3 show the results of first phase of testing conducted in nondieselized coal mines. Results of the data obtained from a typical Sierra impactor measurement are shown in Table 1. This table shows the weight and concentration of dust collected in each size range of the impactor. In many cases relationships between sample results obtained by various gravimetric dust samplers have not been established. As a result consistency in comparing measurements from different instruments can be obtained by comparing percentage determinations based on the individual instrument measurements. The British Medical Research Committee (BMRC) (Hatch, 1964) respirable dust concentration was chosen to estimate the respirable dust concentration from the impactor measurement. The calculated BMRC respirable dust concentration is also given in the table.

Table 2 shows typical summary data from an entire sampling package. This data includes the concentration in each size range for each of the four impactors, the average, standard deviation of the dust concentrations and coefficient of variation (standard deviation expressed as a percent of the average concentration), average total and respirable gravimetric concentrations and BMRC respirable dust concentration. Also given are the calculated values of the submicron concentrations as a percent of the BMRC respirable dust concentrations. For the 22 impactor measurements taken during this phase of testing the average ratio of submicron to BMRC concentration was 0.087 with a standard deviation of ± 0.055.

This indicates that approximately 10 percent of the respirable dust concentration is attributed to submicron size particulate in nondieselized coal mines.

The precision of the impactor measurements was determined as the variability of several impactors for measuring the total dust concentration, the variability of individual impaction substrate and the variability of all impaction substrates. The standard deviation and coefficient of variation for a set of four impactor measurements were considered indicators of the variability of an impactor measurement. The coefficient of variation was used to compare performance in different aerosols. Table 3 gives a summary of the coefficient of variation for each of the impactor data sets along with the average and standard deviation for all of the six sets. The coefficient of variation is the standard deviation divided by the average, expressed as a percent. Also given is the coefficient of variation of the total dust collected by the Sierra 298 and the submicron (less than 0.9 micrometer) portion of the impactor sample.

The coefficient of variation for the total dust sample collected by the impactor ranged from 4 to 25 percent. Except for one set of measurements, the coefficient of variation was less than 16. The average of the coefficients of variation for the total impactor dust measurement was 12 percent. The average coefficients of variation for the individual impaction plates ranged from 20 to 45 percent. The average of the coefficients of variation for all the plates was 34 percent. The coefficients of variation of the submicron plates ranged from 17 to 47 percent with an average coefficient of variation for the submicron plates of 28 percent.

TABLE 2. IMPACTOR STUDY DATA SUMMARY

DATE 1/06/88
MINE MINE 2-B

IMPACTOR SUMMARY

ECD UM	CONC. MG/M3 IMP 1	IMP 2	IMP 3	IMP 4	AVERAGE MG/M3	STD.DEV MG/M3	COF.VAR. %
21.000	0.303	0.253	0.329	0.477	0.341	0.096	28.175
15.000	0.316	0.297	0.310	0.365	0.322	0.030	9.323
10.000	0.592	0.508	0.626	0.658	0.596	0.065	10.907
6.000	1.121	1.192	1.044	0.937	1.073	0.109	10.155
3.500	0.569	0.679	0.673	0.492	0.603	0.090	14.920
2.000	0.697	0.558	0.477	0.584	0.579	0.091	15.716
0.900	0.056	0.068	0.042	0.045	0.053	0.012	22.718
0.500	0.016	0.010	0.013	0.013	0.013	0.002	18.600
0.000	0.027	0.015	0.008	0.011	0.015	0.008	54.168
TOTAL WT	3.698	3.579	3.521	3.582	3.595	0.074	2.058
SUBMICRON	0.044	0.024	0.021	0.024	0.028	0.011	38.971
BMRC-RESP	1.142	1.085	0.965	0.950	1.036	0.093	8.980
SUB/BMRC	0.038	0.022	0.022	0.025	0.027	0.008	28.479

GRAVIMETRIC SUMMARY

TOT.SAMP	3.711	3.501			3.606		
RESP.SAMP	1.113	0.979			1.046		

TABLE 3. SUMMARY OF IMPACTOR SUBSTRATE COFFICIENT OF VARIATION, PERCENT

ECD UM	MINE 1-A	MINE 1-B	MINE 2-A	MINE 2-B	MINE 3-A	MINE 3-B	AVERAGE
21.00	26.37	29.06	47.68	28.17	49.39	55.10	39.30
15.00	13.43	12.78	56.72	9.32	15.93	42.72	25.15
10.00	13.22	24.31	25.26	10.90	12.74	36.14	20.43
6.00	50.81	32.10	90.40	10.15	29.02	58.57	45.18
3.50	17.39	27.00	57.01	14.92	60.69	70.76	41.30
2.00	30.43	30.98	30.08	15.71	53.50	49.52	35.04
0.90	6.75	34.46	43.58	22.71	41.57	62.63	35.28
0.50	27.67	19.53	19.24	18.60	20.90	46.60	25.42
0.00	32.84	24.28	21.73	54.16	81.53	24.32	39.81
AVERAGE	24.32	26.06	43.52	20.52	40.59	49.60	34.10
	13.35	6.77	22.78	14.05	23.00	14.16	
IMPACTOR TOTAL	4.03	14.54	15.86	2.05	14.69	24.58	12.62
IMPACTOR SUBMICRON	20.91	21.21	16.71	38.97	46.80	24.19	28.13

TABLE 4. COMPARATIVE IMPACTOR MEASUREMENTS- DIESELIZED COAL MINE

DATE 8/16/88
FLOW RAT 2.000 LPM
OP. TIME225.000 MIN

MSHA IMPACTOR-1.0MM	PLATE		FILTER		----MRE EQUIVALENT----			
SAMPLE NO.	INIT.WT. MG	FIN.WT. MG	INIT.WT. MG	FIN.WT. MG	PLATE CONC. MG/M3	FILTER CONC. MG/M3	RESPIR. CONC. MG/M3	PERCENT SUBMIC %
1	374.788	375.150	12.364	12.875	1.110	1.567	2.677	42.416
2	369.194	369.519	12.468	12.847	0.997	1.162	2.159	39.011
3	366.854	367.062	12.498	13.057	0.638	1.714	2.352	52.813
4	361.345	361.803	12.539	13.135	1.405	1.828	3.232	40.976
5	372.499	373.005	12.557	12.990	1.552	1.328	2.880	33.415
6	369.843	370.340	12.527	12.939	1.524	1.263	2.788	32.844
7	364.151	364.625	12.499	12.946	1.454	1.371	2.824	35.170
8	381.486	381.694	12.541	12.980	0.638	1.346	1.984	49.168
AVERAGE					1.165	1.447	2.612	40.726
STD.DEV.					0.379	0.232	0.415	7.267
COF.VAR.					32.557	16.005	15.875	17.843

	GRAVIMETRIC SAMPLES		298 IMPACTORS			
	TOTAL CONC. MG/M3	RESPIRABLE CONC. MG/M3	SUPMIC CONC. MG/M3	SUBMIC CONC. MG/M3	BMRC CONC. MG/M3	PERCENT SUBMIC %
1	7.447	2.912	1.183	0.873	2.056	42.461
2	4.579	1.686	1.075	0.776	1.851	41.923
AVERAGE	6.013	2.299	1.129	0.825	1.954	42.192
STD.DEV.			0.076	0.069	0.145	0.380
COF.VAR.			6.764	8.319	7.420	0.901

These values indicate that the variability of the submicron impaction plates is similar to the variability of the other impaction substrates. However the variability of the impaction plates appears to be more than the variability of the total dust collected in the impactor. This was attributed to possible impaction plate overloading and the resulting particle bounce from stage to stage. The use of a preseparator on an impactor sample may reduce the particle bounce and reduce variability in the respirable size range.

Results of the second phase of the testing on the MSHA impactor are given in Tables 4 and 5. Results of an individual test conducted on the MSHA impactors and the associated Sierra 298 are summarized in Table 4. The respirable concentrations were determined from the average of the two respirable dust concentrations obtained from the approved coal mine dust samplers. The submicron percentage for the MSHA impactor was obtained by dividing the submicron concentration by the respirable dust concentration multiplied by 1.38 (Tomb, 1973). The submicron percentage for the Sierra 298 was obtained by dividing the submicron concentration by the British Mining Research Council (BMRC) concentration determined from the impactors. Also shown in Table 4 are the average and standard deviation of the submicron percentage obtained with the Sierra 298 and the MSHA impactors.

A summary of the results obtained on the MSHA impactor are compared in Table 5. The samples collected with the MSHA impactor in Mines A, C, D and E were obtained using a thin coat of grease on the impaction plate. In Mines A, D and E the weight of dust impacted was greater than 0.5 mg. This resulted in an overload of the impaction plate and in an overestimate of the submicron percentage. Samples from Mine C and Test 3 Mine D were also collected using a thin coat of grease on the impaction plate. In these cases the weight of dust on the impaction plate was less than 0.5 mg and the submicron percentage agreed with the results from the Sierra 298. In Mines B and F the impaction plate was coated with a thick layer of grease (approximately 100 milligrams). This thick coating of grease reduced the particle bounce from the impaction plate. In these cases samples with impaction plate weight gains exceeding 0.5 mg agreed with the Sierra 298. Although the relationship between the MSHA and Sierra 298 submicron measurements varied for impactor loading greater

TABLE 5. - SUMMARY OF RESULTS OF EVALUATION OF MSHA IMPACTOR

	TEST	RESPIRABLE DUST CONCENTRATION MG/M^3	AVERAGE PERCENT SUBMICRON SIERRA 298	MSHA 0.8 MM	MSHA 1.0 MM	STANDARD DEVIATION MSHA IMPACTOR % SUBMICRON
MINE A NONDIESEL	1	2.28	13.4	38.4	--	± 7.2
	2	1.74	7.4	38.4	--	± 7.3
MINE B NONDIESEL	1	1.42	4.0	11.6	--	+5.8
MINE C DIESEL	1	2.29	42.2	--	40.7	± 7.3
	2	1.54	47.8	37.2	--	± 5.0
	3	3.07	40.1	--	42.7	± 6.3
MINE D DIESEL	1	4.36	21.2	--	50.8	± 5.2
	2	5.27	19.2	33.1		± 1.1
	3*	0.58	57.1	49.7	--	± 0.9
MINE E DIESEL	1	7.46	26.1	--	47.4	±10.0
	2	2.26	23.3	57.1	--	±10.2
	3	9.46	24.6	--	52.2	± 8.9
MINE F DIESEL	1*	1.62	27.8	--	49.1	± 1.3

* INTAKE MEASUREMENT.

than 0.5 mg, the standard deviation of the MSHA impactor submicron determination was less than 10 percent.

Results from these tests indicate that a thick coat of grease can be used to increase the capacity of the impaction plate and reduce particle bounce. An alternative or supplement to increased impaction plate greasing would be to utilize a multiple jet impaction device. This would give several dust deposits on the impaction plate which would also increase capacity and reduce particle bounce. A multiple jet single stage submicron impactor has been developed by the University of Minnesota under a grant from the U. S. Bureau of Mines Minerals Industry Generic Dust Center Program. This impactor is expected to provide a respirable as well as a submicron measurement and should reduce problems associated with particle bounce and impaction plate overloading.

The use of multiple jets also reduces the pressure drop across the sampling head. The pressure drop across the 0.8 mm orifice sampling head is approximately 21 inches of water gauge. The pressure drop on a multiple jet impactor is inversely proportioned to the two-thirds power of the number of jets ($P \propto 1/n^{2/3}$). As a result an 8-jet impactor would have approximately one-quarter the pressure drop of a single jet impactor.

SUMMARY

Result of studies conducted in underground coal mines indicate that impaction devices may have the potential to separate the submicron from the respirable fraction of the aerosol. Tests conducted with the Sierra 298 multistage impactor indicate that approximately 10 percent of the respirable dust concentration in nondieselized coal mines is due to particles less than 1.0 micrometer.

Tests for precision, conducted with a single stage, single jet impactor show that submicron percentage measurements can be reproduced ±10 percent. Overloading of the single jet impactor can occur unless the plate is heavily greased. The pressure drop across the single jet impactor can be greater than 20 inches of water.

The multiple jet, single stage impactor developed by the University of Minnesota, offers several advantages over a single jet impactor.

The multiple jet single stage impactor should increase the dust loading capacity of the instrument and reduce the pressure across the sampling head. This instrument must be field tested to determine the performance in nondiesel mines, to determine the repeatability and to determine the dust loading capacity.

REFERENCES

Cantrell, B. K., 1987, "Source Apportionment Analysis Applied to Mine Dust Aerosols: Coal Dust and Diesel Emissions Aerosol Measurements," Proceedings of Third Mine Ventilation Symposium, Pennsylvania State University.

Hatch, T. F. and Gross, P., 1964, Pulmonary Deposition and Retention of Inhaled Aerosols, AIHA, New York.

Lodge, Jr., J. P. and Chan, T. L., 1986, Cascade Impactor Sampling and Data Analysis, AIHA, Akron.

NIOSH, 1988, "Carcinogenic Effects of Exposure to Diesel Exhaust," NIOSH Current Intelligence Bulletin 50.

Rubow, K. L., et al., 1980, "Measurement of Coal Dust and Diesel Exhaust Aerosols," Proceedings of VIIth International Pneumoconiosis Conference, NIOSH, Pittsburgh.

Stanevich, R., et al., 1988, "Method for Determining the Contribution of Diesel Particulate to the Respirable Dust Levels in Underground Coal Mines," Society of Mining Engineers Preprint No. 88-60, Phoenix.

Tomb, T., et al., 1973, "Comparison of Respirable Dust Concentrations Measured with MRE and Modified Personal Gravimetric Sampling Equipment," U. S. Bureau of Mines RI 7772.

U. S. Department of Labor, 1988, "Report of the Mine Safety and Health Administration Advisory Committee on Standards and Regulations for Diesel-Powered Equipment in Underground Coal Mines."